Implementation of different RF-chains to drive Acoustic-Optical Tunable Filters in the frame of an ESA space mission

Abstract

The ALTIUS-instrument is a three-channel spectral imager, measuring in the ultraviolet (250 nm to 450 nm), visible (440 nm to 800 nm) and near infrared (900 nm to 1800 nm) wavelength domains, that is bound to fly aboard a PROBA-satellite.
The ALTIUS-project (satellite and instrument) is developed under the supervision of ESA and with funding of Belgian Science Policy (BELSPO). The goal of the ALTIUS-instrument is to make hyper spectral images of the limb of the earth. To do this, the instrument will use different observation techniques such as "direct limb viewing", "stellar occultation" as well as "solar occultation".
The intention is to use an AOTF (Acousto-Optical Tunable Filter). The AOTF is used as a passband selector making it possible to scan fast and randomly through the spectral domain. The AOTF is the key element of the instrument's front end optics. As spectral slices of the incoming light are rhythmically passed to a two dimensional detection system, ALTIUS is capable of generating hyperspectral images of the observed scene. Using an AOTF, especially in the UV-range brings challenges on the RF-generating level. The electronics for this need to produce a rather high frequency in comparison with the available RF-generating techniques for space applications.

For each of the three AOTFs, an RF-generator/amplifier will be developed, each with its own specifications on resolution, sensitivity, frequency range, electrical and optical performance. The electronics will be designed and manufactured to survive several years in a space environment. It needs to pass a suite of environmental tests such as thermal-vacuum, vibration, radiation, shock and EMC. The choice of electronic components, the PCB-design and manufacturing needs to be in accordance with "space qualified" standards.

For the design of an AOTF RF-generator different approaches were investigated. In the frame of the space environment and the applicable restrictions concerning power, voltage levels, mass and volume two appropriate solutions were chosen, namely the Hilbert transform and the PLL approach.

In the analog Hilbert transform solution the combination of a space qualified fixed oscillator with a space qualified Actel-Microsemi RTAX-FPGA will reach the desired frequency ranges for the three channels. This FPGA is, at this moment in time, the only available space qualified FPGA which fulfils the scientific needs in the frame of the project. The clock frequency of this device is 127 MHz. Power consumption is around 1 W.
Inside the FPGA a DDS (Direct Digital Synthesizer) has been integrated. The DDS in combination with a space qualified Texas Instruments DAC (Digital to Analog Convertor) produces an output sine wave of 0 to 30 MHz. This DAC can operate at a clock rate up to 400 MSa/s and consumes typically 660 mW when used at the highest clock rate.
This master signal will be combined with a fixed oscillator of 90 MHz leading to a driving frequency for the Visible channel between 60 and 120 MHz. The spectrum contains a lot of spurious signals, depending on the used frequencies. The multiple mixing of the signals and summing at the end of the chain creates these undesired signals. Further tests have to be carried out to investigate the impact of this non-pure sinewave on the optical performance of the instrument. One possible solution will

be the limiting of the signal after the summing device. The consequence will be a higher power consumption. The spectral image reveals the suppression of the undesired signals by -30 dBc, which fulfils the desired requirement stated by the mission.

For the NIR channel the use of a fixed space qualified oscillator of 45 MHz in combination with the master output of the DDS-DAC (here running at a frequency between 0 and 15 MHz) fulfils the requirements. This combination leads to a driving frequency between 30 and 60 MHz.

Finally for the UV-channel a switchable fixed space qualified oscillator of 165 MHz and 235 MHz will be used in combination with the DDS-DAC (here running at a frequency between 0 and 35 MHz). By combining these two devices, a driving frequency of 130 to 260 MHz can be achieved. The advantage of using a switchable oscillator is that more than one octave can be covered. The switching between the two oscillators has to be performed by an HF-switch which is also tested and investigated at breadboard level. Simulation and hardware testing show that the desired requirements concerning switching speed and stability can be fulfilled.

The conceptual design of the approach with the different oscillators has already been performed for the three channels and has already been simulated, prototyped and tested. It is proven that the requirements put forward for the RF-chains are achievable. Currently the unwanted spectral components in the RF-output for all three channels are -30 dBc. The inserted losses caused by the different devices is around 15.4 dB for each channel, without the use of the extra limiter at the end of the chain. Further research is carried out to improve the spectral purity of the produced sine waves.

Another possible solution is a design which involves a high frequency Phase Locked Loop (PLL). The combination of a space qualified frequency synthesizer integrated circuit of Analog Devices together with a voltage controlled oscillator (VCO), an active loop filter and a space qualified prescaler of Peregrine Semiconductor can fulfil the requirements for the UV-channel.
The generated signal of the VCO can be controlled between 1 GHz and 2.4 GHz. By the use of a divide-by-8 prescaler the desired frequency range for the UV-channel can be reached (130 to 260 MHz). Current tests have been performed on the UV-channel concept. The results of the achieved spectrum is in line with the requested requirements. The spectrum is free of excessive harmonics and spurs. The generated second harmonic is less than -22 dBc, the third harmonic is -10dBc. By adding an additional filter, these signals can be suppressed. A passive 3th order band pass hourglass filter is used to further block the second harmonic. Of course this has an impact on the power level of the generated RF-signal. An additional attenuation of about 10 dB will be present.
The same VCO can be used in combination with a divide-by-8 and a divide-by-2 prescaler to reach the desired frequency range for the Visible channel (60 to 120 MHz). No space qualified divide-by-16 prescaler exists, so a combination of two dividers is necessary. These tests will be performed in the near future. If the VCO frequency range is adapted from 1 GHz to 2 GHz, a divide-by-8, combined with a divide-by-4 prescaler has to be used to reach the frequency range of the NIR-channel (30 to 60 MHz). Using only one prescaler gives the same spectral result. The result is definitely fulfilling the requirements. Further investigation concerning the stability of this spectrum and other parameters is still needed. Combining two prescalers to produce the desired output frequencies has an impact on

the spectral components of the output signal. The effects on the output spectrum of the Visible channel are part of future investigation.

The two proposed solutions both have their pros and cons. For the Hilbert transform the number of used building blocks is higher than for the PLL-solution. This has an impact on the amount of used space on the PCB. Also the complexity rises and the reliability decreases if more building blocks are used. The more blocks used, the higher the mass will be. For vibration and shock testing this has a major impact. The position and mass of the different building blocks has to be examined in relation to the anchoring points of the PCB in the frame. Depending on which kind of launcher vehicle chosen, the amount of G-force will vary. This will determine the way of positioning the building blocks and also the way in which the blocks are secured on the PCB. This item has to be investigated and determined in the future of the project.

The power levels also differ for both solutions. Both the PLL and the Hilbert transform use an oscillator as a basic driving device. Looking at the power consumption for this building block, this will be the same for both solutions.

The Hilbert transform will have an estimated power consumption for the FPGA and the two DACs of around 2.2 W. In relation to the introduced loss of around 15.4 dBm, this is the most power consuming solution.

The PLL-solution uses a frequency synthesizer which consumes around 100 mW. The prescaler will consume around 40 mW each. Of course we would still need an additional FPGA to drive the frequency synthesizer. It is estimated that this FPGA will consume around 1 W. This is much lower than the Hilbert transform solution.

The achieved output levels for the two solutions (Hilbert transform around -12 dBm, the PLL-solution around +4.6 dBm) have an impact on the design of this RF-amplifier as well.

The spectral purity of the Hilbert transform is not as good as the spectrum of the PLL-solution. Of course further work on the Hilbert transform has to be done to improve this result, but at this moment in time the PLL-solution has a more pure signal. The signal stability, jitter and impact of thermal cycling for the different solutions has to be investigated in future work. Also the harmonic distortion has to be tuned.

From current investigation and breadboarding it seems that the PLL-solution has more advantages than the Hilbert transform. This solution is based on a VCO, which is an analog component influenced by temperature variations. This is a parameter that has to be taken into account. The Hilbert transform doesn’t use a VCO, but has other devices which can be influenced. Depending on the stability of the signal when exposed to thermal cycling and other environmental tests, we need a backup solution as well. This is why the path of the Hilbert transform is not abandoned in this phase of the project